AP2 & Debuncher Acceptance

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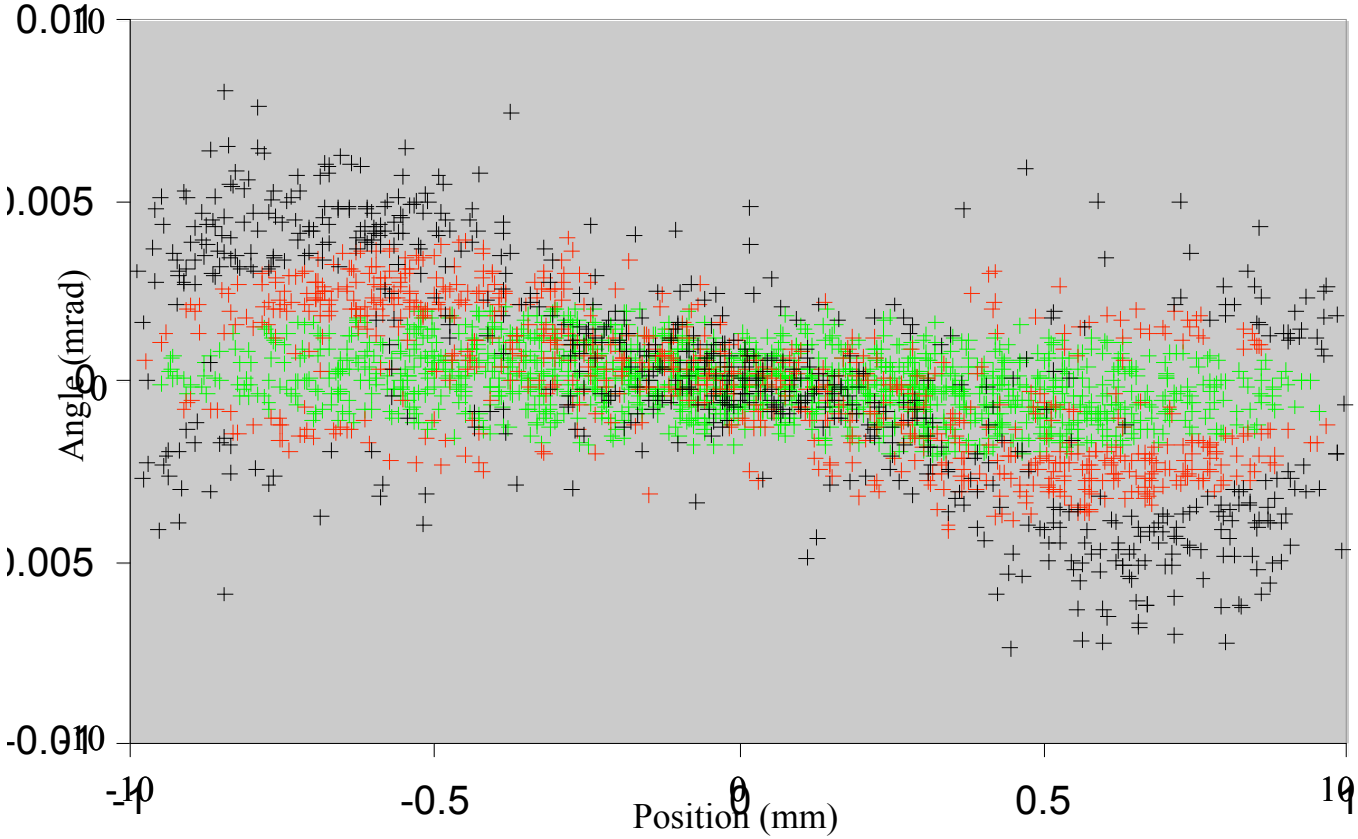
Dept. of Energy Review

February 25, 2004

Outline

- Overview of Goal
- Plan and Status
  - What is new
    - Near completion of aperture documentation
    - Survey as found been performed
    - LBNL study of AP2 and chromatic effects
    - AP2 BPM characterization and studies
    - New Debuncher BPM Data Acquisition
    - Moved DRF3 cavity from dispersion region
    - Change of D4Q4 from build to use existing spares
    - Debuncher extraction kicker as limitation
    - Additional motorized Debuncher quad stands installed
    - Developing "Paint the Aperture" procedure
    - Developed new combined AP2+Deb admittance measurements performed during stacking.
- Overview of Beam Studies & Schedule

Goal: Lots of Pbars to Circulate in Deb.



< 20π mm-mrad

20π-40π mm-mrad

> 40π mm-mrad

Simulation of pbar transverse phase space (both planes) out of a 750 T/m lens.
{2 entries for each pbar that traverses only Lithium part of lens}

35π mm-mrad aperture allows 320π mm-mrad beam emittance

Collect as much as possible for Debuncher Cooling Systems

Realization of 35π mm-mrad

Identify & Understand Restrictions

- Documentation Research
- Optical Survey
- Lattice Modeling
  - LBNL study of AP2 chromaticity
- Instrumentation
- Beam Studies

Mitigate

- Redesign/modify/rebuild specific elements
- Align/relocate specific elements

Beam Based Alignment

- Lattice Model
- Instrumentation
- Orbit control
- Beam Studies

Identifying Limitations and Lattice Models

Identify Restrictions

Building detailed lattice models

Tech Div has performed documentation research

Verifying drawings with components
Produced tables of all apertures

Final Checkout

Optical Survey

Data 90% taken
Crunch numbers

Determine alignment of AP2 & Debuncher components
Determine alignment of AP1, target hall & AP2

Preparing to perform

Verify lattice parameters

Beam studies using upgraded instrumentation

Continue to feed into models

Models (OptiM & MAD)

Local & LBNL investigations

Identify restrictions and orbit control tolerances
Propose resolutions

MAD Model and Studies by LBNL

AP2 Aperture Studies at LBNL

- Simulations to study effect of various machine errors and chromatic effects on acceptance

- Found two possible causes of aperture restrictions. Both have their root in the large momentum spread of $\pm 2.25\,\%$:

  1. Residual vertical dispersion caused by misalignment of quadrupole magnets
  2. Chromatic effects due to large chromatic functions

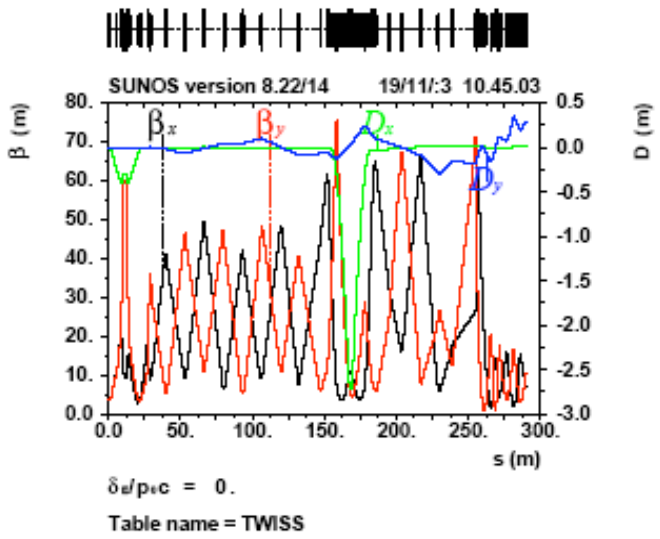
- Suggested experiments for further study; a few mainly parasitic experiments have already been done, but dedicated beam time is required

- Studying possibilities to reduce chromatic effects by adding sextupole magnets

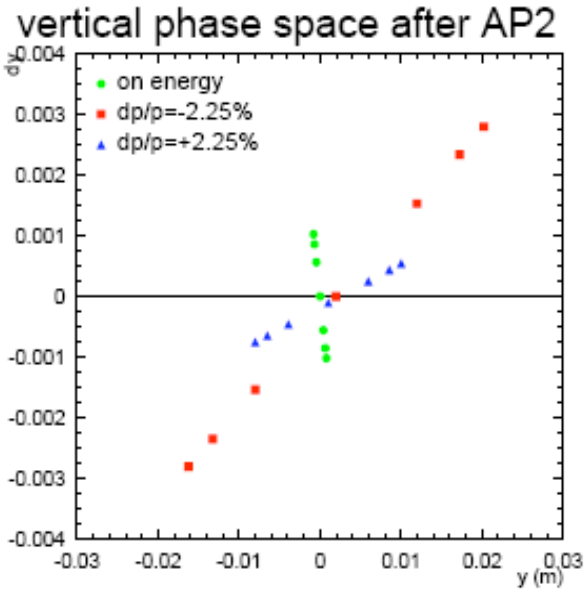
LBNL: I. Reichel, M. Placidi & M. Zisman

MAD Simulations and Studies by LBNL

Simulation Results



- Large residual vertical dispersion can create aperture problems in small vertical apertures at the end of the line

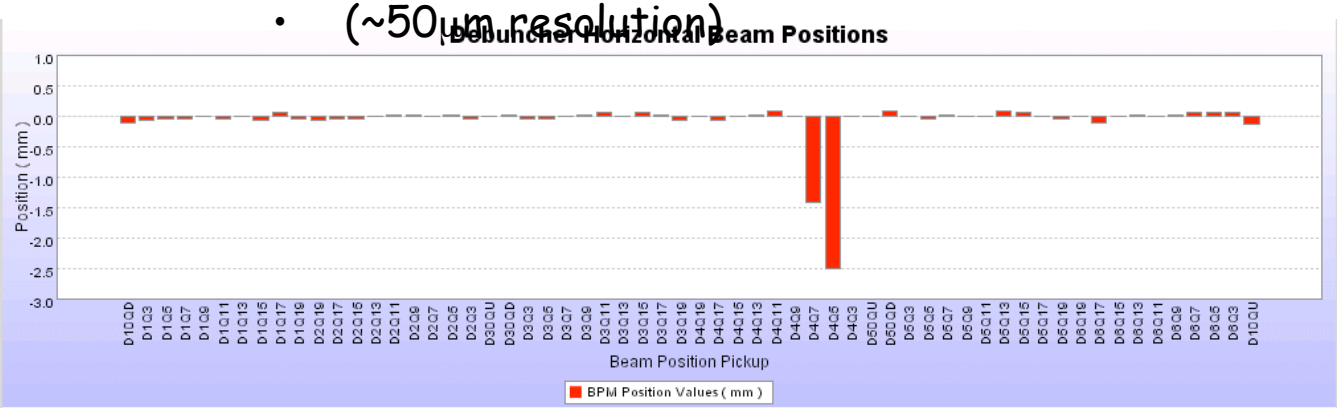


- particles have initial offsets (no angles) corresponding to $0, \pm 12, \pm 28$ and $\pm 40\,\pi$mm mrad
- final amplitudes and phases depend strongly on momentum deviation

Instrumentation

Instrumentation Upgrades

- **Debuncher BPM system**
  - Old original electronics and Data Acquisition.
    - Reliability, maintenance and ease of use were issues
  - New Electronics and Data Acquisition installed
    - 2.5MHz Closed Orbit system
    - (~50μm resolution)



Beam Position Detector Name and Beam Position in Millimeters

D10QD -000.10	D2Q19 -000.06	D30QD 000.03	D4Q19 000.00	D50QD 000.10	D6Q19 -000.00
D1Q3 -000.06	D2Q17 -000.03	D3Q3 -000.03	D4Q17 -000.06	D5Q3 -000.00	D6Q17 -000.10
D1Q5 -000.03	D2Q15 -000.03	D3Q5 -000.03	D4Q15 000.00	D5Q5 -000.03	D6Q15 000.00
D1Q7 -000.03	D2Q13 000.00	D3Q7 000.00	D4Q13 000.03	D5Q7 000.03	D6Q13 000.03
D1Q9 -000.00	D2Q11 000.03	D3Q9 000.03	D4Q11 000.10	D5Q9 000.00	D6Q11 000.00
D1Q11 -000.03	D2Q9 000.03	D3Q11 000.06	D4Q9 000.00	D5Q11 -000.00	D6Q9 000.03
D1Q13 -000.00	D2Q7 000.00	D3Q13 000.00	D4Q7 -001.41	D5Q13 000.10	D6Q7 000.06
D1Q15 -000.06	D2Q5 000.03	D3Q15 000.06	D4Q5 -002.51	D5Q15 000.06	D6Q5 000.06
D1Q17 000.06	D2Q3 -000.03	D3Q17 000.03	D4Q3 000.00	D5Q17 000.00	D6Q3 000.06
D1Q19 -000.03	D30QU -000.00	D3Q19 -000.06	D50QU 000.00	D5Q19 -000.03	D10QU -000.13

Commissioned

Making application user friendly

Example of difference orbit from local bump

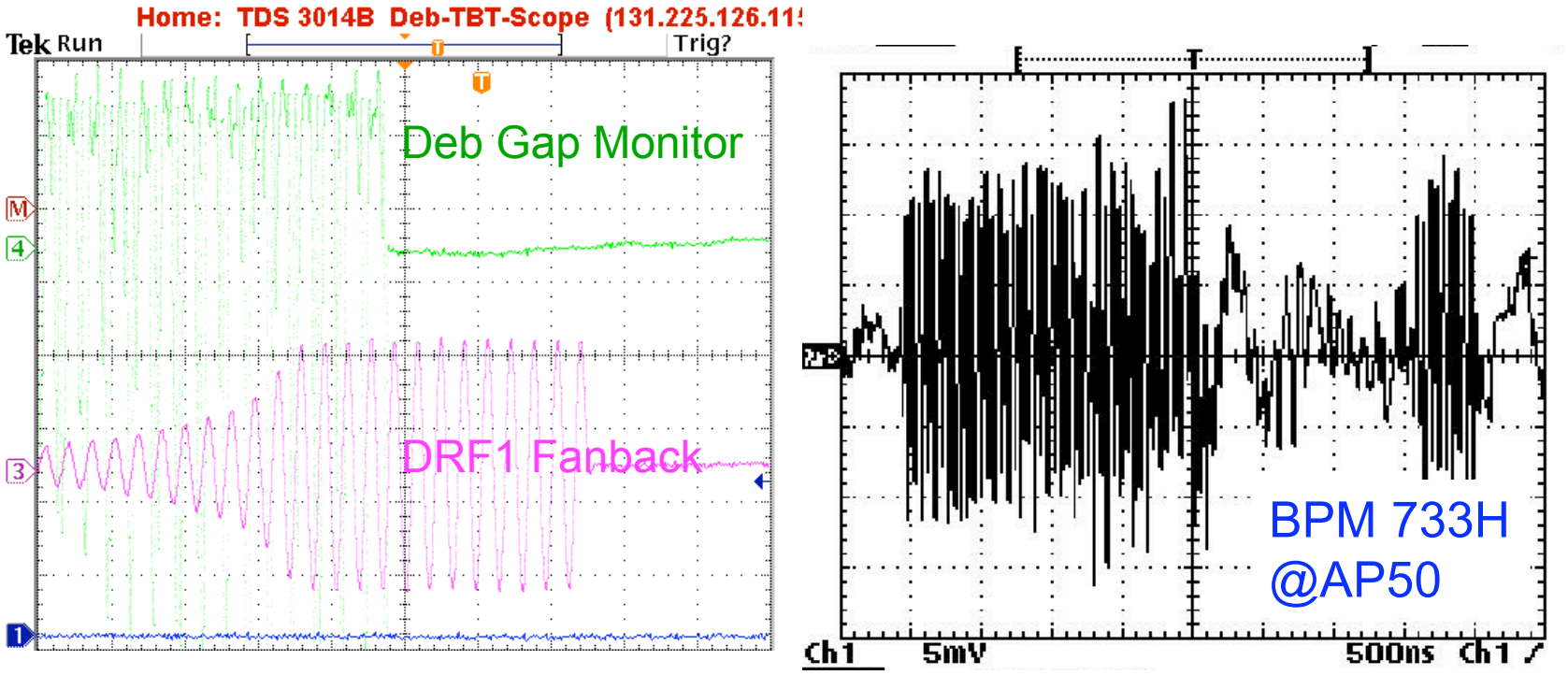
Instrumentation Upgrades

- **AP2 BPM system**
  - Want to make measurements using reverse protons
  - Old original electronics and Data Acquisition.
    - Reliability, maintenance and ease of use are issues
  - Desire <100μm resolution (53MHz)
    - Minimum is DAQ and software replacement
    - *Still* need to see if RF electronics are sufficient

- **Other**
  - Re-install AP2 709 horizontal collimator
    - Was re-installed; no beam studies yet
  - AP2 large aperture Toroid(s)
    - Beam intensity measurement along beam line
      - Started discussions with vendor
  - Study of whether to move SEMs

AP2 BPM Beam Studies

- Observation of 53 MHz modulated reverse proton beam on AP2 BPMs
  - Good signal (~5 mV) on upstream (F27) BPMs
  - Injection kicker noise on downstream (AP50) BPMs



Existing AP2 Instrumentation

System	Stacking	Rev. prot	Fwd. prot	Comment
BPMs (34)		Trying	Yes	Orig AM/PM Mod & DAQ 1/2 of system see kicker
BLMs (0)				System removed several years ago
SEMs (9)	Yes	Yes	Yes	Non-optimal phase advance between SEMs
Intensity (1)	Ion Chamber	Ion Chamber	Ion Chamber	Removed 3inch toroids from 6inch beam pipe
Collim. (5x2)	Yes	Yes	Yes	2 per transverse plane & 1 longitudinal sets
RF for BPMs	From MI	Commis. DRF1 53MHz	From MI	DRF1: Reverse adiabatic cavities curves to "bunch" beam

Existing Debuncher Instrumentation

System	Stacking	Rev. prot	Fwd. prot	Comment
BPMs (120)		Yes Yes	Yes	~~Orig AM/PM Mod & DAQ~~ ~~Hard to maintain & use~~ *New System commissioned*
BLMs (62)	Not really	Yes	Yes	
Intensity (1)		DCCT	DCCT	Measures circulating current
Pickups (5)	Yes	Yes	Yes	2 are used for stacking TBT or studies "heater"
Collim.	Yes	Yes	Yes	1 scraper per plane
RF for BPMs		Re-comm. DRF3 ~~2.5MHz~~	To be used	Studies RF system; new controls

Known Restrictions & Steering Hazards

Known Restrictions

Band 4 cooling tanks arrays

Vertical array gaps were designed for ~30π mm-mrad

Determined that increasing the gap by 3.1mm can be done.

Will decrease frequencies of upper band of system to overlap with lower band; not affect overall cooling.

Move DRF2 & DRF3 to low/zero dispersion region(s)

Radiation surveys show activation

-DRF3 has been re-located to low dispersion.

-Looking into different schemes of where to re-locate DRF2 and essential electronics.

Other restrictions

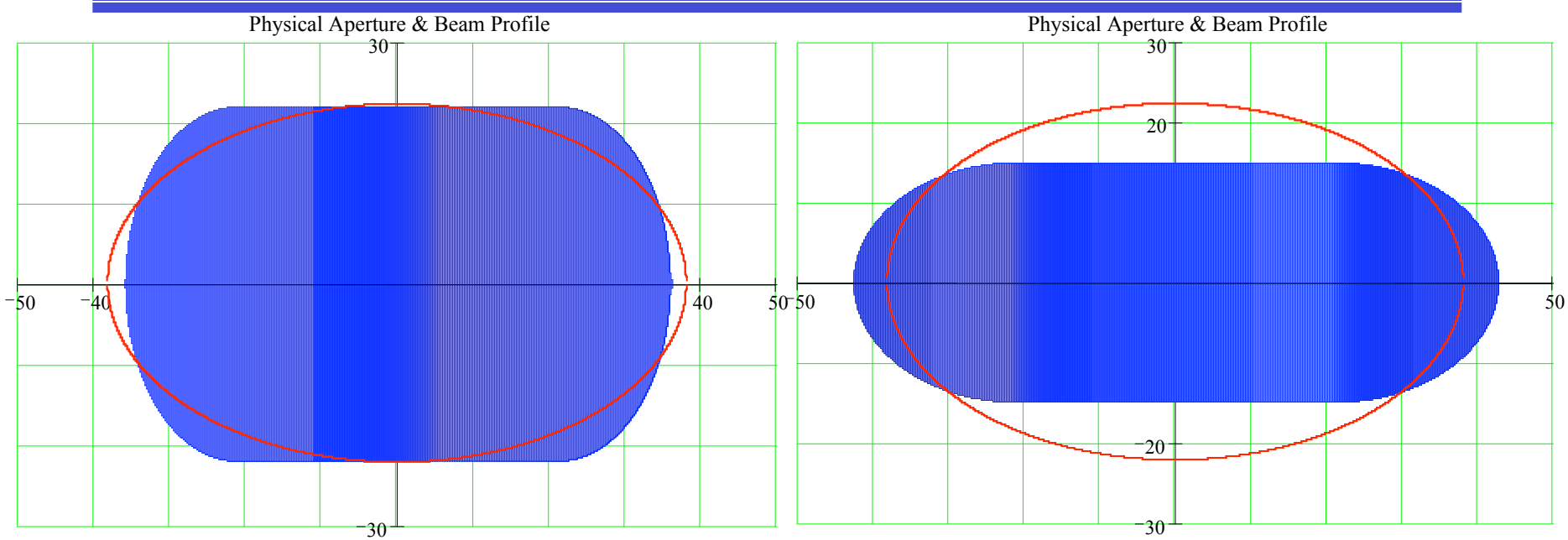
Identification and solutions may have to wait for modeling, beam studies and/or mitigation of other restrictions.

Recently Identified

Identified that the extraction kicker's elliptical pipe is 22π mm-mrad aperture for off momentum particles.

Appears that inserting a rectangular beam pipe will

Debuncher Extraction Kicker



Upstream End – Beam Profile First Turn in Debuncher– **Downstream End**

82% of tracked beam particles inside of current beam pipe (ellipse).

Rectangle of same inner dimensions accepts 91%.

Increase horizontal dimension will accept 95%: Looking into offsetting pipe in kicker, but beam fairly small when extracting (good field region?)

Will also motorize kicker stand to center beam pipe about beam.

Limiting Apertures

Device	Horizontal		Vertical
	$\frac{\pi r r}{\quad}$	$\frac{\pi r r}{\quad}$	
Band 4 Hor. pickup	36.8 π	36.3 π	48.7 π
Band 4 Ver. pickup	40.5 π	39.0 π	29.9 π
Band 4 Hor. kicker	36.0 π	35.5 π	48.7 π
Band 4 Ver. kicker	41.2 π	41.1 π	30.1 π
Deb Extr. kicker	109.1 π	21.9 π	35.8 π

Steering Restrictions

Motorize stands for septum & kickers

Tolerances are small; desire to center devices

Engineering will start by looking at existing tank motorized stands.

Injection septum (common vacuum chamber)

Desire injected beam to be close to closed orbit

Investigating whether spare can be reworked to minimize material at down stream end.

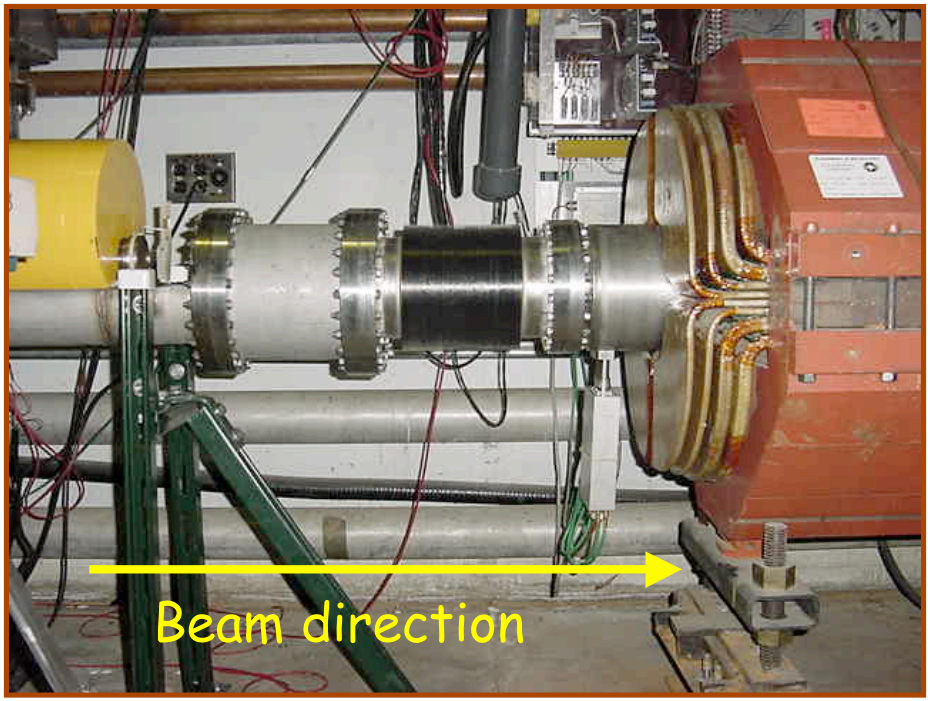
D4Q4 replacement & BPM removal/relocation

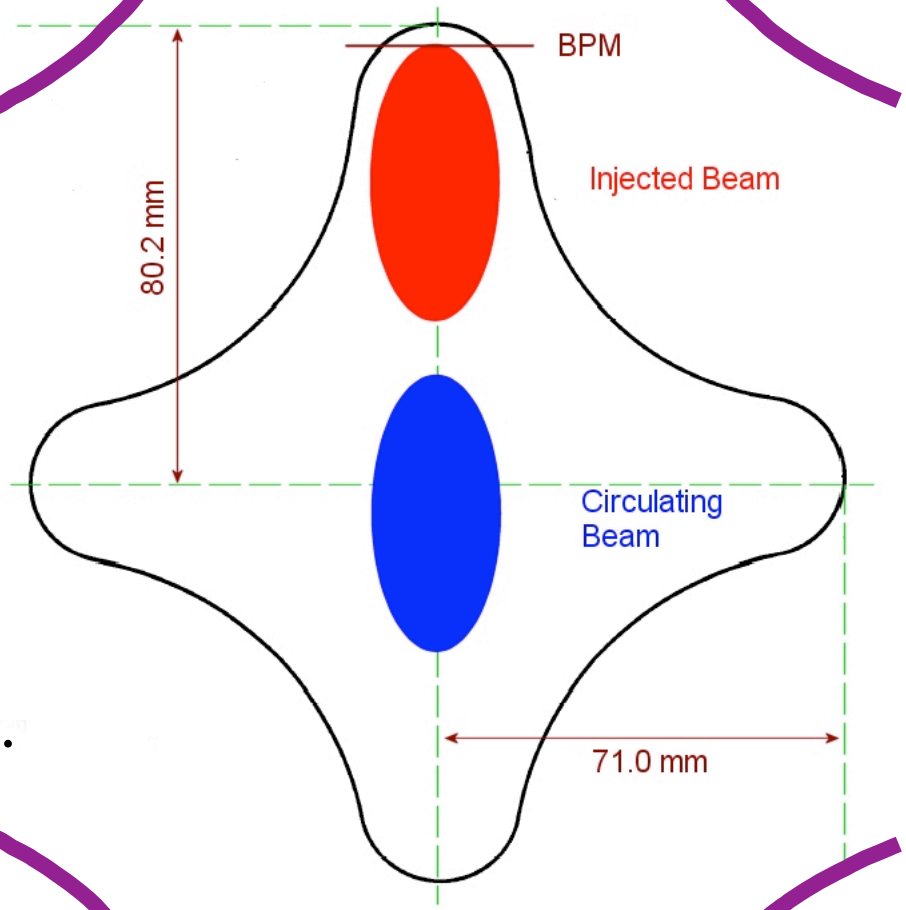
~No vertical tolerance for injected beam

2 large spare quad LQBs will replace quad; same integrated field and fits into space.
Need stand work; have existing power supply.

Change from build to using existing spares

D4Q4 Aperture





No tolerance for injected beam.

Will replace with two **large quad LQBs (pole tips drawn)**; increase vacuum chamber.

Move BPM from upstream area.

Orbit Control

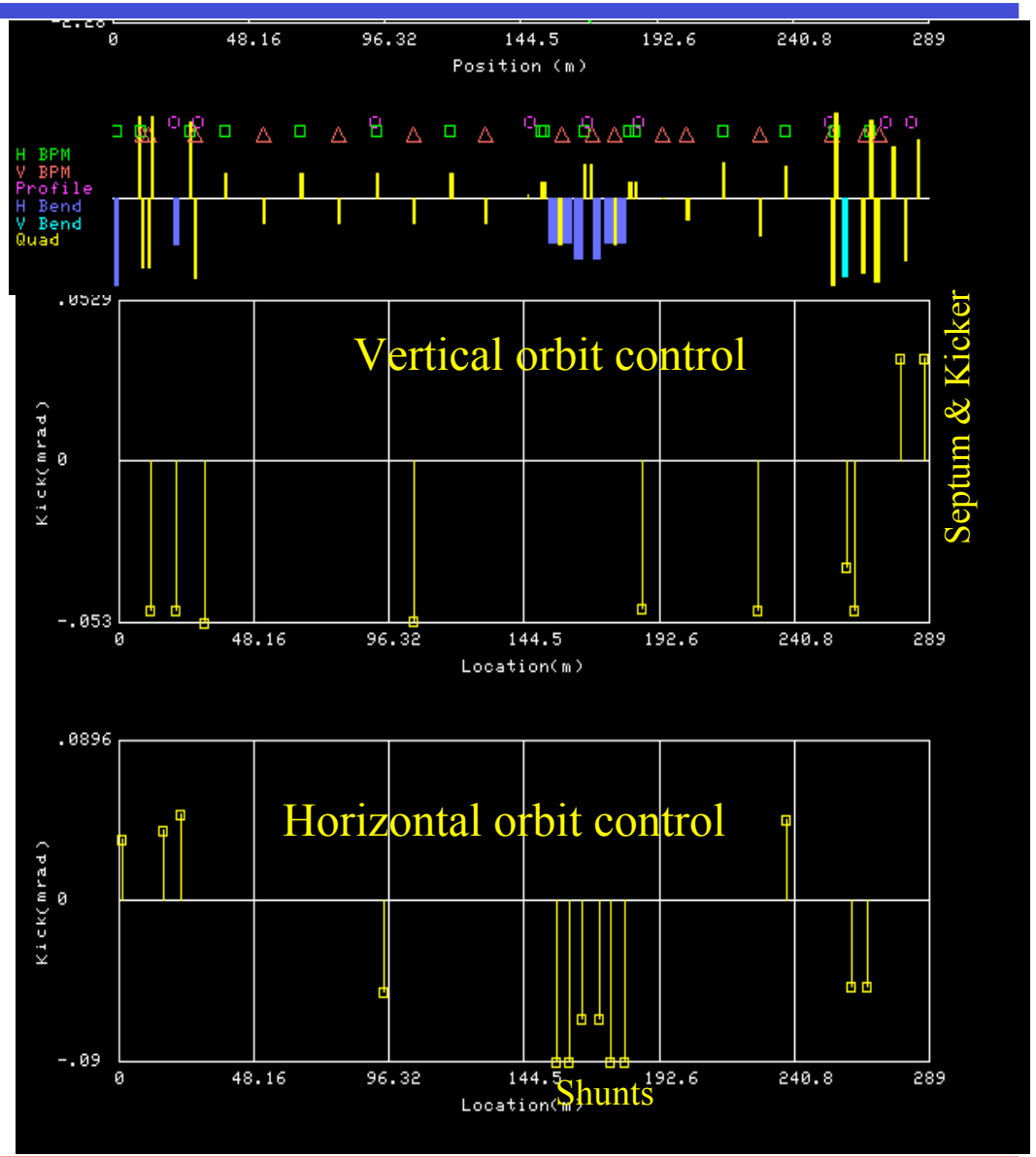
Orbit Control

AP2 Beam Line

Started with 4H+4V trims

Have ***added*** 1H+3V trims. ***Installed*** shunts on all dipoles of left bend

Can add more trims as needed



Orbit Control

Nearly finished with local bump commissioning

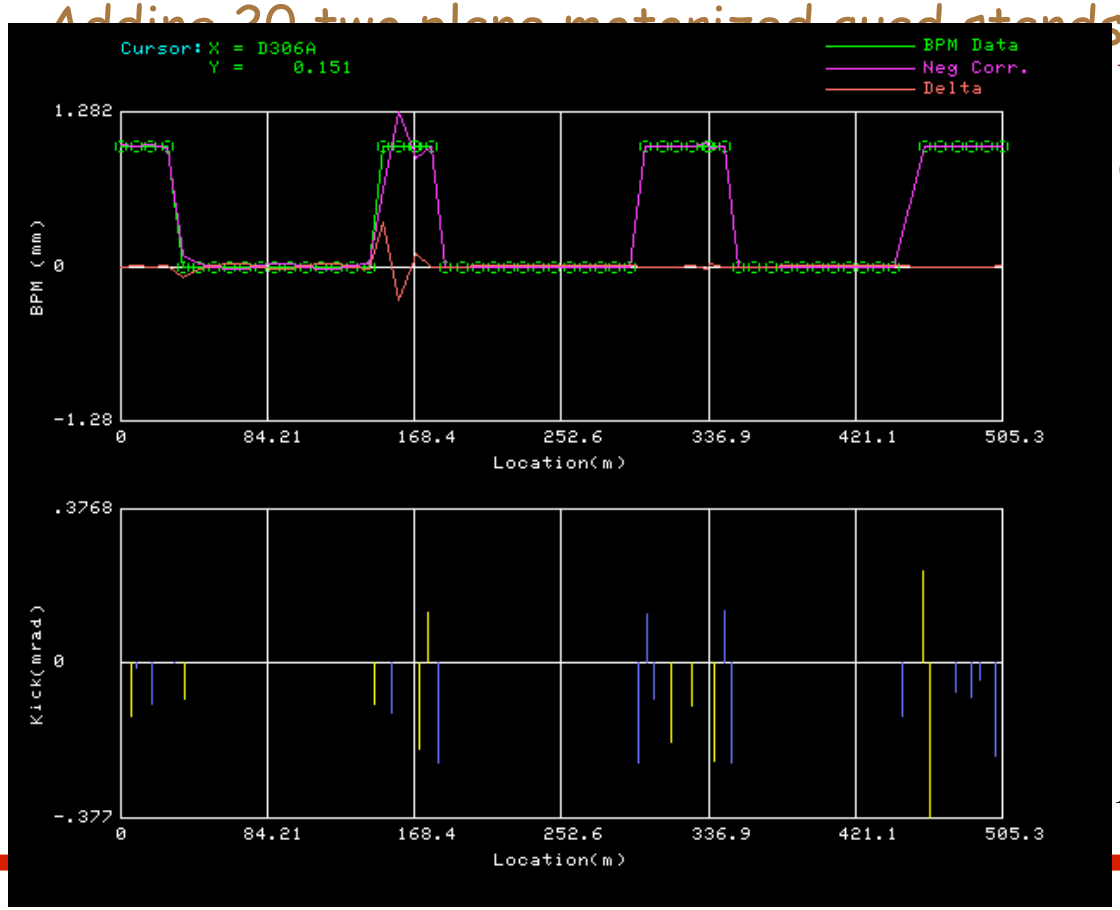
Debuncher

Started with 13H+7V trims & a vert. plane motorized quad

Have added 5 two plane motorized quads (99)

Added 10 two plane motorized quad stands (03)

Adding 20 two plane motorized quad stands (04)



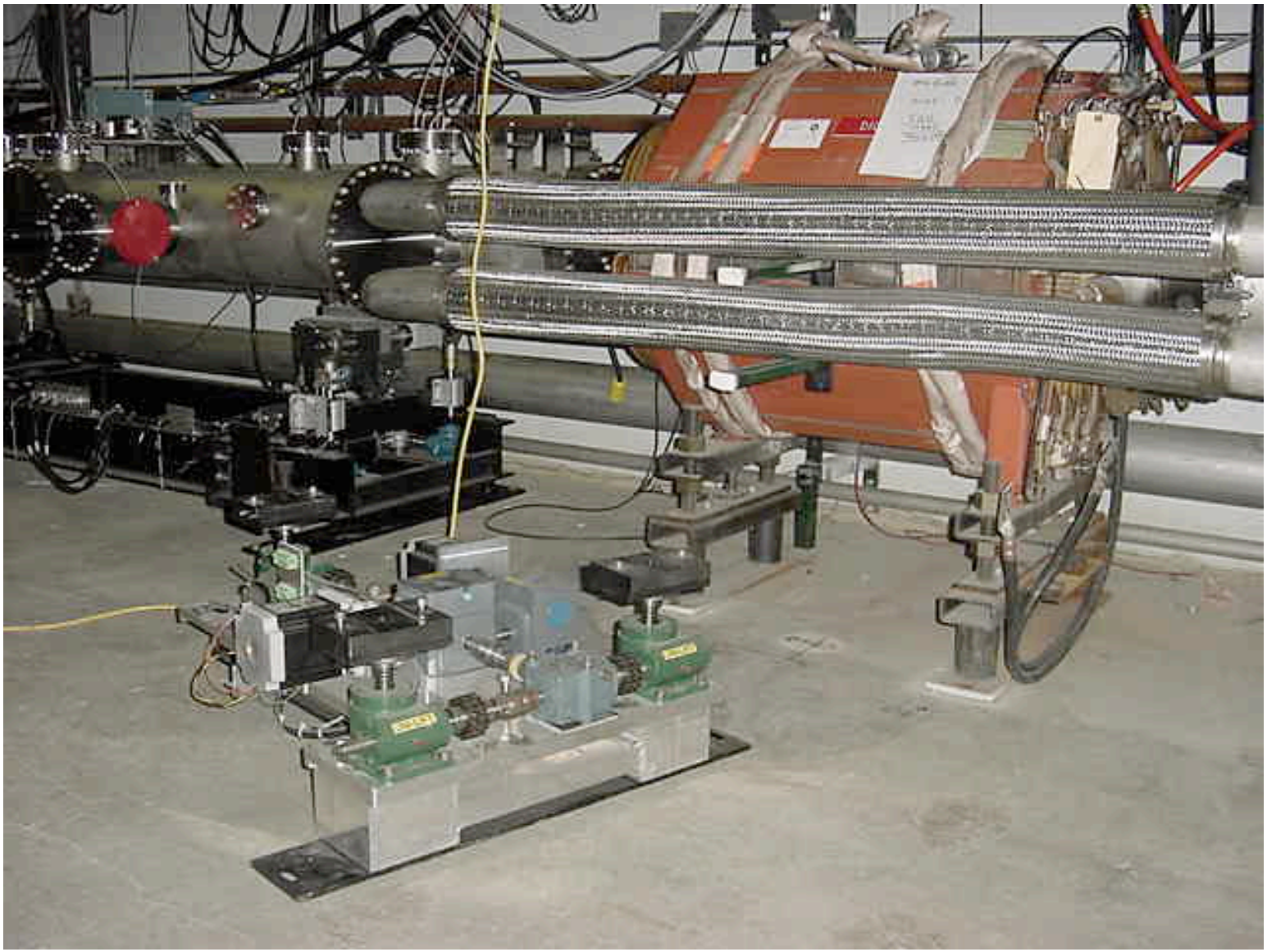
Where the orbit control exists

No available space for trims; the ring is packed

Yellow: Dipole Trims

Blue: Motorized Quads

Shutdown Work – Quad Stands



Beam Based Alignment &
Beam Based Determination of Apertures

Beam Based Alignment

Basic BBA Procedure

Excite a quad

Most quads have shunts

Measure response

BPM systems for proton studies

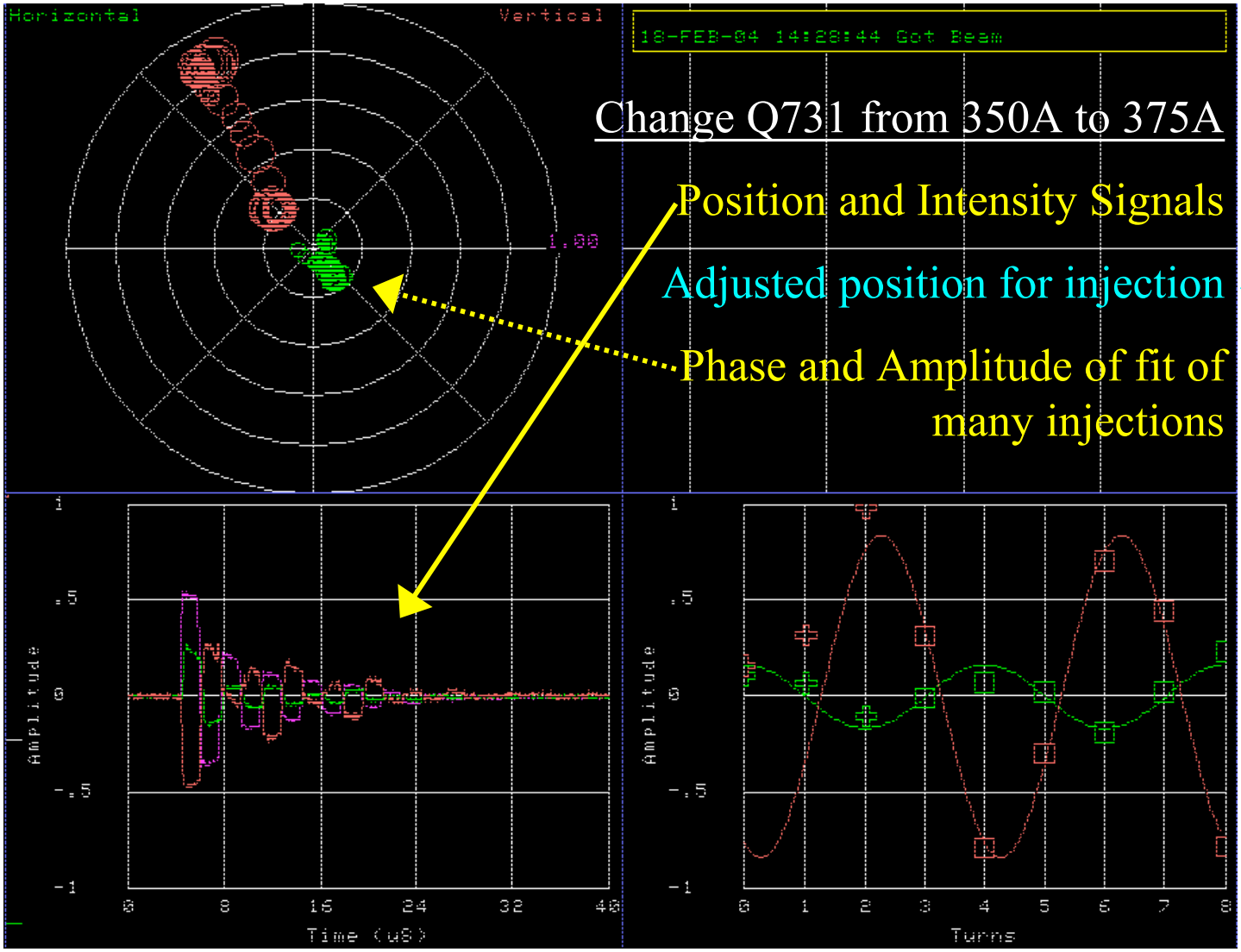
- A Debuncher pickup for AP2 during stacking

Correct Orbit

Trims, shunts, motorized quad stands

Debuncher Turn-By-Turn Instrumentation

Normally use Debuncher TBT with AP2 dipole trims and Injection elements to minimize injection oscillations



Other Study Programs

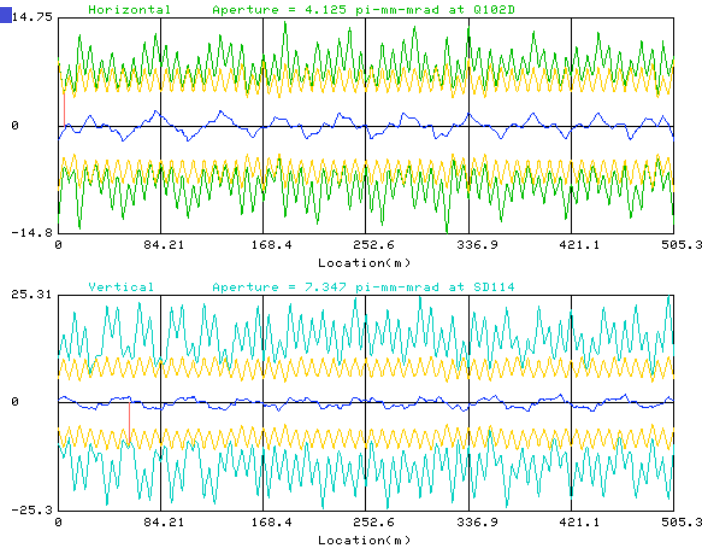
Heat protons in Deb and watch BLMs

- Paint the Debuncher aperture

Prepare known emittance/momentum
reverse proton beam & kick beam up

Paint the Aperture

Not Fully debugged- commissioned in 1999-2000 for Debuncher.



For each corrector, kick until beam is extinguished: then have "painted" the aperture.

Program has no assumptions about beam emittance and distribution, so need to extinguish beam ⇒ each corrector reach is then only about ~4π

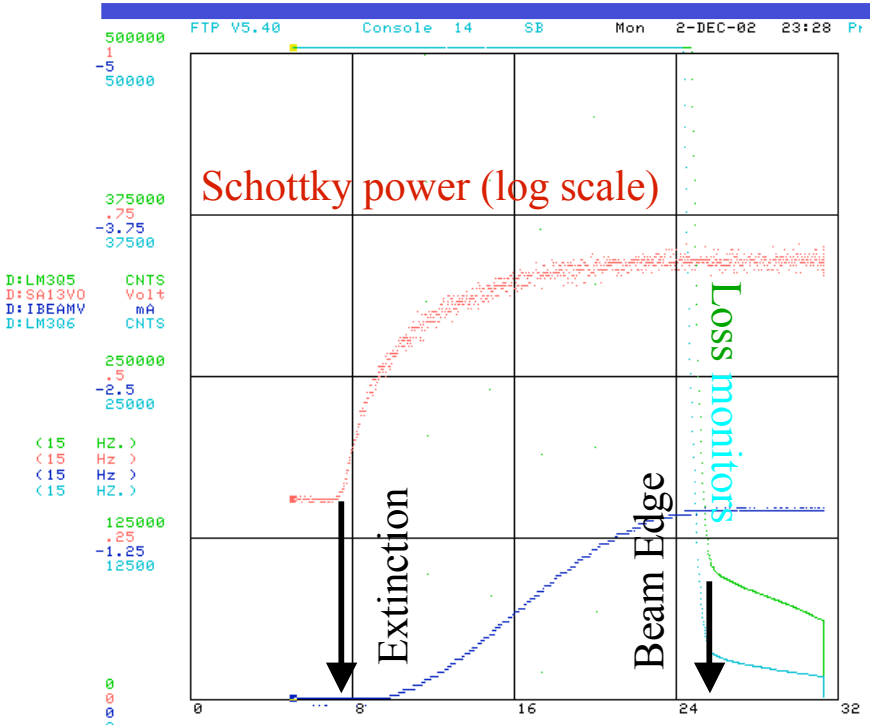
Possible Solutions:

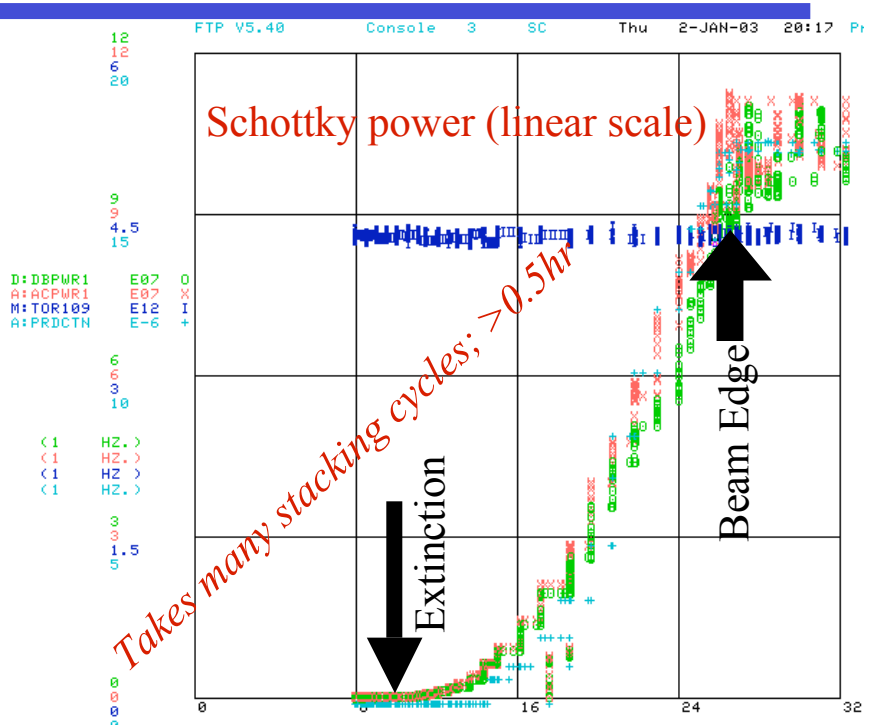
1) Be able to prepare beam to known emittance & distribution consistently before exciting any trim.
2) Use combinations of trims to map out more of the aperture.

The former needs much study time to see if possible;
the latter we have been pursuing…

Admittance Measurement Methods

Admittance Measurements



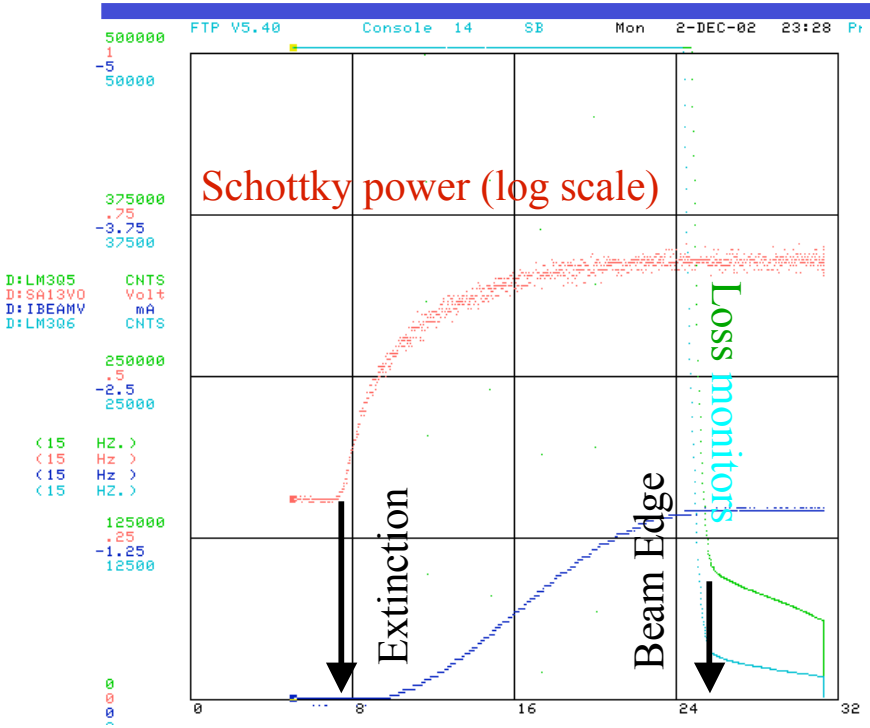


Circulating Admittance done by scraping heated reverse proton beam:

Well defined edge and extinction ($\Delta p/p \sim 0$)

Operational Admittance done by scraping while stacking: Hard to define Beam edge & extinction ($\Delta p/p$ is full mom. spread)

Admittance Measurements



Debuncher horizontal scraper position (mm)

Old Method

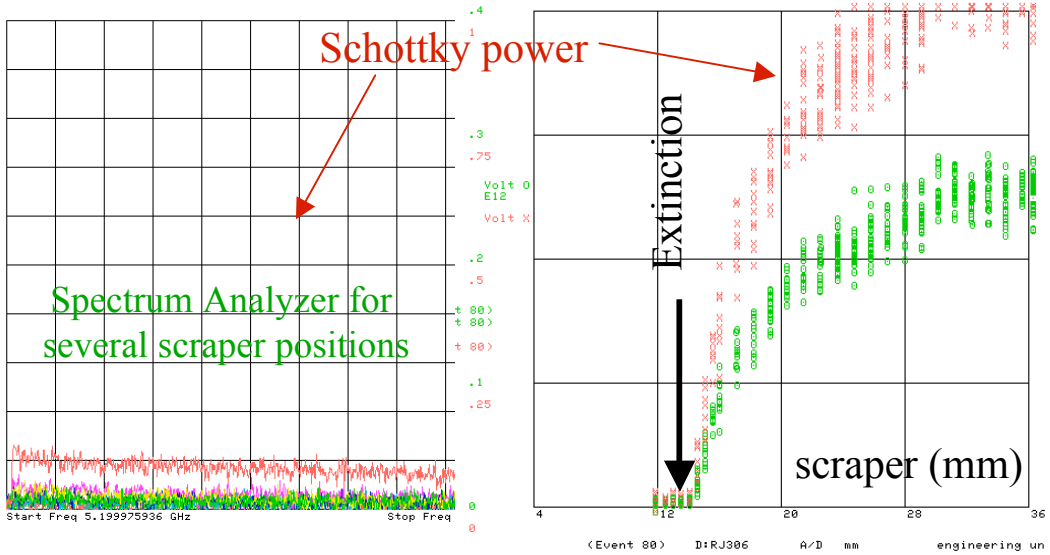
Circulating Admittance done by scraping heated reverse proton beam:

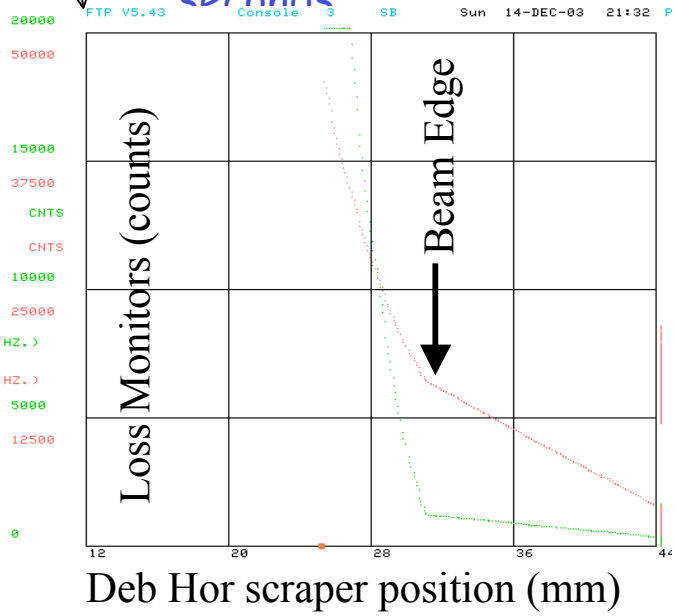
Well defined edge and extinction ($\Delta p/p \sim 0$)

($\Delta p/p$ is full mom. spread)

Operational Admittance Measurements

- Make separate (few minute setup) measurements of the beam edge and extinction point
  - lengthen the production cycle time to 10's seconds





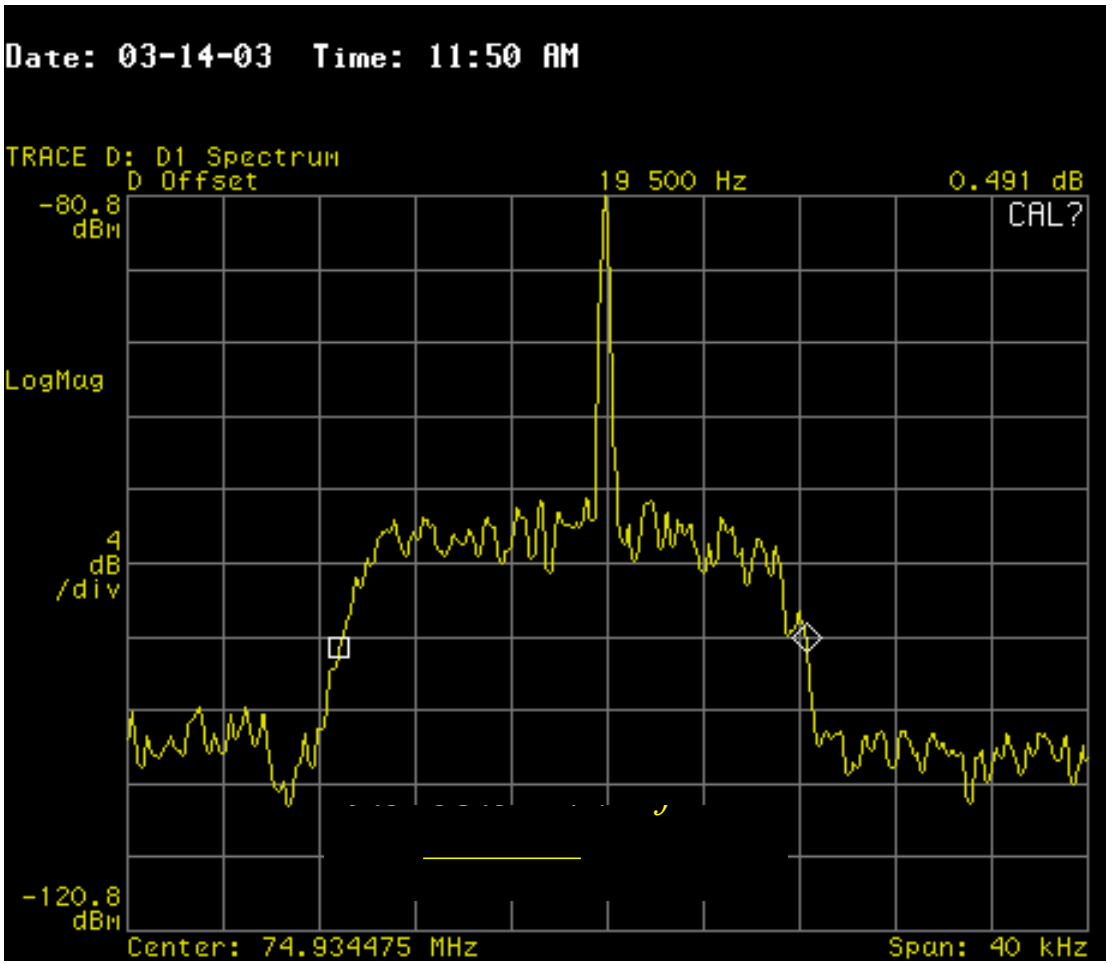
Extinction Point: Schottkey power sampled seconds after injection versus Debuncher scraper; Spectrum Analyzer goes from flat line to small step in the 0.1box of left plot above

Beam edge: Run scraper into beam between cycles starting a few seconds after injection; record loss monitors as function of scraper position

Momentum Acceptance

Longitudinal Schottky profile of $\bar{p}$'s filling the momentum aperture of the Debuncher.

Bunch rotation and stochastic cooling are off.



NOTE: An earlier (11/2002) measurement gives
$\Delta p/p = 4.6\%$

Acceptance

	Measured AP2 + Debuncher (stacking)	Measured Debuncher (rev. prot.)	Smallest Aperture (lit. search)	Goal
Horizontal (mm-mrad)	24 ± 3 π	28 ± 3 π	35.5 π {22 π for off mom.}	35 π
Vertical (mm-mrad)	18 ± 2 π	20 ± 2 π	30 π	35 π
Momentum	±2.15%	±2.30%	--	±2.25%

Beam Studies & Schedule

Near Term Studies List

Gollwitzer Oct 28, 2003

Commissioning/AP2&Debuncher Aperture Beam Studies

Current desired reverse protons studies are shown in the table below along with the needed preceding beam study, whether repeated injections are needed and total time (optimistic and disregards reverse proton setup time).

REVERSE PROTONS BEAM STUDY	PRECED. BEAM STUDY	REPEAT INJECT. (Y/N)	TOTAL TIME (HR)	% Done (Dec 15, 2003)	% Done (Jan 23, 2004)
1. Measure transverse aperture & tunes on nominal orbit		No	1	100	
2. Verify DRF3 bunches beam & measure Debuncher momentum aperture		No	1	100	
3. Verify all new BPMs see intensity, record non-working BPMs; record nominal orbit and motorized quad stand read backs	2	No	1	100	
4. Perform Debuncher 1 bumps using trims and record closed orbits	3	No	2	100	
5. Create difference orbits and look for wrong BPM polarity; fix cabling	4	Offline & Access?	2	100	
6. Each plane of each motorized quad stand: move known amount and record orbit	5	No	8	100	
7. Off mom. meas. ±1, ±2%: DRF3 to move beam, mom. scrape, BPM orbit, measure tune, heat beam, transverse admittance meas.	5	No	6		
8. Develop bumps using trims and motorized quad stands; exercise/verify	6	No	16 +12	40,60	
9. Use Deb bumps to center beam in aperture	8	No	16	20	
10. Kick beam up AP2; verify/record SEMs work and observe beam flag		Yes	1		
11. Setup DRF1 to provide 53MHz as beam is kicked up AP2	10	Yes	1		
12. Time-in upstream AP2 BPM DAQ; record several orbits	11	Yes	4		
13. Vary kick strength and observe beam flag, record SEMs and BPMs	12	Yes	1		
14. Vary septum strength, trims and left bend shunts; record SEMs and BPMs	12	Yes	4		
15. Repeat 11 for off mom. beam: (DRF1 freq.)	11	Yes	2		
16. DRF3 to change beam mom.; DRF1 bunch & kick beam up AP2; record BPMs & SEMs	15	Yes	8		
17. Center or record location of all Debuncher non-quad elements on motorized stands		No	16		
18. Sextuple determination of central freq.	2	No	4		
19. Validate 'Paint the Aperture' program	5	No	16		

Current desired stacking studies are shown in the table below along with the needed preceding beam study, the expected effect on stacking averages over the study period and total time (optimistic).

STACKING BEAM STUDY	PRECED. BEAM STUDY	EFFECT ON STACKING	TOTAL TIME (HR)	
20. Record SEMS and observe beam flag		Parasitic	1	100
21. Center beam in Lens and upstream quads; use SEMs and Debuncher TBT response	20	<25%	16	
22. Center beam in downstream quads and reduce trim dipole currents; use SEMs and Debuncher TBT response	21	<50%	16	5
23. Record AP2+Debuncher momentum acceptance (turn off RF and cooling)	20	Destructive	1	50
24. Measure AP2+Debuncher transverse admittances	20 & periodically	<50%	2	100
25. Exercise re-installed 709 collimator; monitor IC728, INJFLX, production eff	20	<50%	1	
26. Record SEM403 for closed orbit and injection orbit; latter uses Debuncher scraper	20	Destructive	1	
27. Record SEM403 & AP2 SEMs response to AP2 1-bumps; also observe beam flag	26	Destructive	4	10%
28. Set 719 collimators to select 0.5% slice of p/p about 0, ±1, ±2%: record momentum spectrum and measure transverse apertures	23 & 24	Destructive	16	
29. Record AP2 BPM response during stacking (intensity and/or position monitors?)	20	Parasitic	1	
30. Perform and record near-	20	<10%	8	50
31. Perform and record results of dispersion bumps in AP2	20	<50%	4	50
32. Optimize D:EKIK and horizontal bump settings	20 & 9	Parasitic	4	25
33. Optimize lens longitudinal position	22	Parasitic	2	

Not comprehensive. Written early Nov03, planned to complete within 6 months.

Beam Studies Aug03-Feb04

Reverse Proton Studies: majority done during down periods or (recently) when have large stacks (4-6hr block of time).

Commission Debuncher BPM System	15hr
Commission Motorized Quad Stands	9hr
Commission Debuncher Local Bumps	36hr
Debuncher Orbit Correction	7hr
Paint the Aperture development	5hr
Reverse Protons into AP2, AP2 BPMs	6hr

Stacking Studies: depending upon study, 5% to 100% effect on stacking for short periods of time

AP2 π bumps	8hr
Debuncher Turn-By-Turn	4hr
Admittance Measurement development	18hr

Aug-Sep	Nov	Dec	Jan	Feb
10hr	20hr	48hr	10hr	20hr

Total amount of time does not include end effects (reverse proton setup and recovery)

Major Shutdown Work

Shutdown 2004

- Install additional 20 motorized quad stands
- Replace D4Q4
- DRF2 Move

Shutdown 2005

- Wider Band 4 vertical cooling arrays
- Upgraded Debuncher Injection Septum (SD2004 ?)
- Motorized stands for Debuncher injection & extraction kickers
- Possible modifications to Debuncher extraction kicker (SD2004 ?)
- Possible implementation of AP2 chromatic correction

Shutdown 2006

- New Debuncher extraction kicker (if not modified during SD2005)
- Implement of AP2 chromatic correction (if not implemented during SD 2005)

Summary

Beam Based Alignment will do the job:

- Upgrade instrumentation
- Better orbit control
  - AP2 beam line
    - Had 13 knobs, have added 10, can add a few more
  - Debuncher ring
    - Had 21 knobs, have added 30, will add 40 more
- As understanding of the lattices improve
  - so do the physical apertures & tolerances
- Upgrade/new software applications

Will mitigate limiting apertures

Redesign/modify/rebuild/relocate

AP2 Debuncher Accumulator Delivery